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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se référer à la description.)

System, receiver and method of operation for spread OFDM wireless communication

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SYSTEM, RECEIVER AND METHOD OF OPERATION FOR SPREAD OFDM
WIRELESS COMMUNICATION

5 **Field of the Invention**

This invention relates to multicarrier wireless communication systems, and more specifically Orthogonal Frequency Division Multiplex (OFDM) modulation schemes.

10

Background of the Invention

Such modulation schemes are now widely used in standards
15 as a means to provide high data rates for communication systems including wireless local area networks (WLANs): 'IEEE 802.11a' in USA and 'HIPERLAN/2' in Europe, ADSL (Asynchronous Digital Subscriber Line) over twisted pairs and 'HomePLUG' on powerlines.

20

For the next decade, the challenge is to deliver an increased data rate coping with the requirements of multimedia broadband transmissions. None of the existing standards will be able to meet these requirements on a
25 larger scale (involving many users) which motivates the search for more robust yet simple modulation schemes that, combined with an appropriate decoding algorithm, show better performance in terms of Packet Error Rate (PER) than classical OFDM systems. This technical
30 criterion translates directly into increased system throughput (rather than capacity). Clearly, an attractive property for such a new modulation scheme would be for it

to be viewed as a simple extension of OFDM so that it could be implemented in existing standards as a proprietary transmission mode. In this way it could also provide a means for smooth transition to new standards.

5

In the field of this invention, enhancements have been proposed as a workaround for alleviating an inherent OFDM weakness: when a carrier is subject to a strong channel attenuation, even in absence of noise, the data conveyed is irremediably lost. The classical alternative is to use forward error correction (FEC) coding to spread the information along the carriers, but another strategy has been proposed: to combine the strength of OFDM and CDMA by pre-processing the block of symbols to be transmitted by a unitary spreading matrix W (often chosen to be a Walsh Hadamard transform for its attractive implementation properties) prior to the FFT/IFFT (Fast Fourier Transform/Inverse FFT) modulation.

20 This redundantless precoder W has the role of uniformly spreading the information to be transmitted on all the carriers so that even if one carrier is unrecoverable, the information transmitted can still be retrieved by decoding of other subbands.

25

Implementations of such spread OFDM (SOFDM also known as single user OFDM-CDMA with cyclic prefix) modulation techniques require successive interference cancellation (SIC), and many SIC algorithms have been proposed. One of the most well known is 'V-BLAST' proposed by Bell Labs for multiple antennas systems in the publication by G.J. Foschini and M.J. Gans, "On Limits of Wireless

Communications in a fading Environment when Using
Multiple Antennas", *Wireless Personal Communications*
6:311-335, 1998. However, it has been demonstrated (in
the publication by P. Loubaton, M. Debbah and M. de
5 Courville, "Spread OFDM Performance with MMSE
Equalization", in *International Conference on Acoustics,
Speech, and Signal Processing*, Salt Lake City, USA, May
2001) that V-BLAST algorithms are not suited for
conventional SOFDM systems due to the averaging of the
10 SNRs (signal/noise ratios) at the receiver across the
carriers during the despreading step. Moreover, such
approaches lead to a tremendous decoding complexity due
to the computation of several pseudo inverse matrices.

15 A need therefore exists for an OFDM communication system
and decoding algorithm for use therein wherein the
abovementioned disadvantage(s) may be alleviated.

20 **Statement of Invention**

In accordance with a first aspect of the present
invention there is provided a spread OFDM wireless
communication system as claimed in claim 1.

25 In accordance with a second aspect of the present
invention there is provided a spread OFDM wireless
communication system as claimed in claim 7.

30 In accordance with a third aspect of the present
invention there is provided a receiver, for use in a

spread OFDM wireless communication system, as claimed in claim 8.

In accordance with a fourth aspect of the present
5 invention there is provided a receiver, for use in a spread OFDM wireless communication system, as claimed in claim 13.

In accordance with a fifth aspect of the present
10 invention there is provided a method, of operating a receiver in a spread OFDM wireless communication receiver, as claimed in claim 14.

In accordance with a sixth aspect of the present
15 invention there is provided a method, for performing minimum mean square error equalization in a spread OFDM wireless communication system, as claimed in claim 19.

In one aspect, the present invention provides a new,
20 efficient yet simple, low complexity decoding algorithm for an enhanced OFDM modulator.

Preferably the OFDM modulator is based on a Walsh-Hadamard transform, allowing exploitation of the
25 mathematical properties of a Walsh-Hadamard precoder.

In one form, the new decoding algorithm consists in splitting a received block into two equal parts, one of the parts being decoded first and then subtracted from
30 the received vector to suppress part of the interference and the other of the parts being decoded next. This iterative procedure can be further extended by successive

block splitting and results in a multi-resolution decoding algorithm. An attractive property of this algorithm is that although it still relies on the computation of pseudo-inverses, the expressions of these
5 pseudo-inverses are easy to derive and consist simply in the product of a diagonal matrix by a Walsh Hadamard transform. Thus, using Walsh Hadamard spreading sequences, the inherent complexity penalty of a V-BLAST decoding schemes is simply removed. This allows a
10 significant gain in performance (e.g., around 3-4dB compared to MMSE SOFDM) with only a modest increase in complexity, which motivates:

- i) the use of such new modulation schemes in practice and
- 15 ii) their proposal as a solution for future wireless LAN standards.

The following technical merits of the new multi-resolution decoding algorithm can be highlighted:

- 20 • Low arithmetical complexity compared to existing SIC BLAST techniques with same or better performance.
- Flexibility and scalability of the method (it is possible to adjust the number of iterations to be performed based on a performance/complexity
25 tradeoff).
- Can be combined into all OFDM standards as a proprietary transmission mode (since it can be viewed as a simple extension of current OFDM systems)
- 30 • Yields a significant PER performance enhancement compared to classical OFDM and minimum mean square error (MMSE) SOFDM receivers (e.g., 3dB).

Brief Description of the Drawing(s)

- 5 One OFDM single user communication system and decoding algorithm for use therein incorporating the present invention will now be described, by way of example only, with reference to the accompanying drawing(s), in which:
- 10 FIG. 1 shows a block schematic diagram of a OFDM-CDMA (spread OFDM) single user communication system;
- FIG. 2 shows a block schematic representation of the system of FIG. 1 modeled in the frequency domain;
- 15 FIG. 3 shows a diagrammatic binary tree representation of the two-stage multi-resolution decoding algorithm used in the system of FIG. 1;
- 20 FIG. 4 and FIG. 5 show graphical representations of simulation performance of the multi-resolution decoding algorithm compared with other decoding scenarios under different respective channel profiles in terms of BER (bit error rate) as a
- 25 function of $\frac{E_b}{N_0}$ (energy per bit / noise energy).

Description of Preferred Embodiment(s)

- 30 As will be explained below, the decoding algorithm to be described significantly enhances performance

compared to MMSE equalized SOFDM scheme, with a complexity excess that is marginal compared to V-BLAST decoding strategies.

5 Consider the dimension $N \times 1$ vector s representing the block of complex valued symbols to be transmitted (each one belonging to a finite alphabet called constellation, e.g., QPSK, QAM, etc.). The overall Spread-OFDM transmission system of interest depicted
10 in FIG. 1 includes, in a transmitter, a spreading matrix module 110, a module 120 providing modulation, a module 130 providing guard interval insertion and parallel-to-serial conversion, and a digital-to-analog converter 140. The transmitter is coupled via a
15 wireless communication channel 150 to a receiver including a mixer and analog-to-digital converter 160, a module 170 providing guard interval suppression and serial-to-parallel conversion, a module 180 providing demodulation, and a module 190 providing demodulation.

20

The system of FIG. 1 can be modelled directly in the frequency domain as illustrated in FIG. 2 so that the received vector y expresses as:

$$y = HWs + b = Ms + b$$

25 where:

H is a $N \times N$ diagonal matrix, bearing the complex frequency channel attenuations,

W is a $N \times N$ unitary Walsh Hadamard spreading matrix, whose particular recursive structure is
30 exploited in the decoding algorithm to reduce complexity,

b is a $N \times 1$ complex white IID (independent and identically distributed) Gaussian noise vector whose component variance is $E[|b_k|^2] = \sigma^2$. (E stands here for expectation)

5

In the following analysis, H , W and σ^2 are assumed to be known at the receiver by any given classical estimation technique.

10 The procedure described below deals with the retrieval of the information vector s based on the received vector y which is referred as the equalization step. Instead of using a traditional MMSE equalizer, a specific successive interference cancellation
15 algorithm (termed a 'multi-resolution decoding algorithm') will be described. In the following analysis, $()^h$ is defined as the Hermitian transpose operator and I_N is defined as the $N \times N$ identity matrix.

20 The multi-resolution decoding algorithm is based on the following steps:

- (i) Decode the received y vector by an MMSE equalizer followed by a non-linear decision function denoted by $dec()$ (e.g., hard decision
25 demapper, soft decision, etc.) $\hat{s} = dec(G_{MMSE} y)$ where $G_{MMSE} = M^h (M M^h + \sigma^2 I_N)^{-1}$ (convenient implementations of the product $G_{MMSE} y$ are detailed below).
- (ii) Split the vector \hat{s} in two equal size $N/2$ parts

30
$$\hat{s} = \begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \end{bmatrix}.$$

- (iii) Subtract the second half \hat{s}_2 of the vector \hat{s} from the received vector y to remove the interference generated by the first half of s (treating s_2 as if $\hat{s}_2 = s_2$).
- 5 (iv) Perform an MMSE equalization of the resulting y_1 half-sized vector by matrix G_1 , followed by the decision function $dec()$ for obtaining a more reliable estimate $\hat{\hat{s}}_1$ of s_1 than \hat{s}_1 .
- (v) Possibly reiterate the procedure, this time on
10 the first half of \hat{s} for retrieving a better estimate $\hat{\hat{s}}_2$ of s_2 than \hat{s}_2 .
- (vi) These operations can be repeated substituting \hat{s}_1 and \hat{s}_2 by $\hat{\hat{s}}_1$ and $\hat{\hat{s}}_2$ respectively
- 15 Translated into equations, this amounts to the following steps:

First stage (310) of the multi-resolution decoding algorithm

20

Step 0, (300) : MMSE equalization of $y: \hat{s} = \begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \end{bmatrix} = dec(G_{MMSE}$

$y)$

Step 1 : $y_1 := y - M \begin{bmatrix} 0 \\ \hat{s}_2 \end{bmatrix} = M \begin{bmatrix} s_1 \\ s_2 - \hat{s}_2 \end{bmatrix} + b$

Step 2 : MMSE equalization of $\hat{\hat{s}}_1$: $\hat{\hat{s}}_1 = dec(G_1^{(1)} y_1)$

25 Step 3 : $y_2 := y - M \begin{bmatrix} \hat{\hat{s}}_1 \\ 0 \end{bmatrix} = M \begin{bmatrix} s_1 - \hat{\hat{s}}_1 \\ s_2 \end{bmatrix} + b$

Step 4 : MMSE equalization of $\hat{\hat{s}}_2$: $\hat{\hat{s}}_2 = dec(G_2^{(1)} y_2)$

$$\text{Step 5 : } \hat{s} = \begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \end{bmatrix} := \begin{bmatrix} \hat{\hat{s}}_1 \\ \hat{\hat{s}}_2 \end{bmatrix}$$

Step 6 : go to Step 1

It should be noted that although as stated above only
 5 a subdivision by two of the received vector y is
 performed, in its more generalized form the procedure
 can apply to smaller subdivisions of y of length N
 divided by a power of 2: $N/2^k$ for any integer k such
 that the result remains an integer. The generalized
 10 algorithm consists in reiterating the procedure
 already explained to each resulting sub-block of y .
 Let stage i of the algorithm define the operations
 performed for a level of subdivisions of y in blocks
 of size $N/2^i$.

15

As an illustration, the second stage of the proposed
 multi-resolution algorithm results in the following
 operations:

20 *Second stage (320) of the multi-resolution decoding
 algorithm*

$$\text{Step 0: form } \hat{s} = \begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \\ \hat{s}_3 \\ \hat{s}_4 \end{bmatrix}$$

$$\text{Step 1 : } y_1 := y - M \begin{bmatrix} 0 \\ \hat{s}_2 \\ \hat{s}_3 \\ \hat{s}_4 \end{bmatrix} = M \begin{bmatrix} s_1 \\ s_2 - \hat{s}_2 \\ s_3 - \hat{s}_3 \\ s_4 - \hat{s}_4 \end{bmatrix} + b$$

Step 2 : MMSE equalization of $\hat{\hat{s}}_1$: $\hat{\hat{s}}_1 = \text{dec}(G_1^{(2)} y_1)$

$$\text{Step 3 : } y_2 := y - M \begin{bmatrix} \hat{s}_1 \\ 0 \\ \hat{s}_3 \\ \hat{s}_4 \end{bmatrix} = M \begin{bmatrix} s_1 - \hat{s}_1 \\ s_2 \\ s_3 - \hat{s}_3 \\ s_4 - \hat{s}_4 \end{bmatrix} + b$$

Step 4 : MMSE equalization of \hat{s}_2 : $\hat{s}_2 = \text{dec}(G_2^{(2)} y_2)$

$$\text{Step 5 : } y_3 := y - M \begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \\ 0 \\ \hat{s}_4 \end{bmatrix} = M \begin{bmatrix} s_1 - \hat{s}_1 \\ s_2 - \hat{s}_2 \\ s_3 \\ s_4 - \hat{s}_4 \end{bmatrix} + b$$

Step 6 : MMSE equalization of \hat{s}_3 : $\hat{s}_3 = \text{dec}(G_3^{(2)} y_3)$

$$5 \quad \text{Step 7 : } y_4 := y - M \begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \\ \hat{s}_3 \\ 0 \end{bmatrix} = M \begin{bmatrix} s_1 - \hat{s}_1 \\ s_2 - \hat{s}_2 \\ s_3 - \hat{s}_3 \\ s_4 \end{bmatrix} + b$$

Step 8 : MMSE equalization of \hat{s}_4 : $\hat{s}_4 = \text{dec}(G_4^{(2)} y_4)$

Step 9 : $\hat{s} := \hat{s}$

Step 10 : go to Step 1

- 10 Note that $G_i^{(\gamma)}$ denotes the MMSE equalizer matrix at stage γ for the sub-block r of vector y of size $N/2^\gamma$.

It is important to note that each stage can be sequenced in many ways following the graphic illustration of FIG. 3 using a binary tree. Each path in the binary tree results into another instantiation of the proposed algorithm. The depth in terms of number of stages and the number of times each of the stages has to be iterated can be determined by a complexity/performance trade-off criterion.

15

20

Thus in order to refine the decoding, the same mechanisms can be applied to blocks of size $N/4$, and then $N/8$, etc. leading to a higher resolution of the decoding.

5

Clearly, increasing the number of stages and iterations yields a more robust estimation procedure. However, simulations show that the bit error rate converges after a few iterations, so to improve again the decoded vector, fortunately in practice only the second stage of the algorithm needs to be considered.

10

A fast algorithm for computing the product of vector y_i by matrix $G_i^{(\gamma)}$ be implemented as follows.

15

Firstly, the expression of matrices $G_i^{(\gamma)}$ is examined, by fairly assuming that at each stage:

20

- $E([s_k - \hat{s}_k][s_k^H - \hat{s}_k^H]) \approx \rho(p_k)I_{N/2^r}$
- $E(s_k \hat{s}_{k'}) \approx 0$ for $k \neq k'$
- $E(\hat{s}_k b^H) \approx 0$

where E is the expectation operator and ρ is a function of p_k , the bit error probability for the k^{th} block after its last equalization, depending on the constellation used.

25

Under these assumptions, it is possible to calculate the expression of the MMSE equalization matrix used at each stage:

$$G_k^{(\gamma)} = \begin{bmatrix} 0 & \frac{N}{2^r} \times \frac{(k-1)N}{2^r} & \frac{I_N}{2^r} & 0 & \frac{N}{2^r} \times \frac{(2^r-k)N}{2^r} \end{bmatrix} M^H (MD_k^{(\gamma)} M + \sigma^2 I_N)^{-1}$$

where $D_k^{(\gamma)}$ is the following block-diagonal matrix :

$$D_k^{(\gamma)} = \text{diag} \left(\rho(p_1) I_{\frac{N}{2^\gamma}} \quad \dots \quad \rho(p_{k-1}) I_{\frac{N}{2^\gamma}} \quad I_{\frac{N}{2^\gamma}} \quad \rho(p_{k+1}) I_{\frac{N}{2^\gamma}} \quad \dots \quad \rho(p_{2^\gamma}) I_{\frac{N}{2^\gamma}} \right)$$

Simulations show that the terms $\rho(p_k)$ do not play an
 5 important role in overall performance, and thus can be
 neglected (replaced by 0), which greatly simplifies
 the calculus of the matrix products. It can be shown
 that in this case, when defining the $\frac{N}{2^\gamma} \times \frac{N}{2^\gamma}$ diagonal
 matrix:

$$10 \quad \Delta_\gamma = \text{diag} \left\{ \frac{1}{\sigma^2 + \frac{1}{2^\gamma} \sum_{k=0}^{2^\gamma-1} |h_{l+kN/2^\gamma}|^2} \right\}_{l=1}^{N/2^\gamma}$$

the following general result is obtained:

$$\begin{bmatrix} G_1^{(\gamma)} \\ \dots \\ G_{2^\gamma}^{(\gamma)} \end{bmatrix} = W \begin{bmatrix} \Delta_\gamma & 0 & 0 \\ 0 & \dots & 0 \\ 0 & 0 & \Delta_\gamma \end{bmatrix} H^*$$

Thus the product by $G_i^{(\gamma)}$ reduces simply to the product
 of y_i by a diagonal matrix depending on the channel
 15 coefficients (computed and stored once only) followed
 by the products of a subset of a Walsh-Hadamard matrix
 of size $\frac{N}{2^\gamma} \times N$. Therefore, the procedure detailed in
 the two previous equations results in a simple low
 arithmetical complexity way for performing the various
 20 MMSE equalizations steps. Instead of the expected
 heavy arithmetic complexity order of N^3 required by the

$G_i^{(\gamma)}$ product, a much simpler complexity of order

$2^\gamma N \log_2 \left(\frac{N}{2^\gamma} \right)$ at each stage results.

The complexity of the multi-resolution decoding
 5 algorithm described above can be estimated as follows.
 The arithmetical simplifications due to the Walsh-
 Hadamard structure lead to quite a low complexity. At
 each stage γ of the algorithm, the complexity $C(\gamma, N)$ of
 one iteration (i.e., 2^γ calculus of y , of $G_i^{(\gamma)} y$ and
 10 decisions) can be overestimated:

$$C(\gamma, N) \approx N \left(2^\gamma \left(2 \log_2 \left(\frac{N}{2^\gamma} \right) + 6 \right) + 2 + \frac{3}{2^\gamma} \right) \times AddR + N \left(3 \times 2^\gamma + 4 + \frac{5}{2^\gamma} \right) \times MulR + N \times Decision$$

where *AddR* is the complexity of an addition of two
 real values (assumed equal to that of a subtraction),
 15 *MulR* is the complexity of a multiplication, and
Decision is the complexity of a hard decision on a
 complex value (the choice of a symbol).

There follows an illustration of the performance
 20 improvement provided by the above-described multi-
 resolution decoding algorithm in the context of a
 5.2GHz, 20MHz bandwidth, 64 carrier with 800ns guard
 time HIPERLAN/2 OFDM system using a QPSK
 constellation. Simulations were run using 2 channel
 25 profiles: (i) a perfect time interleaved BRAN 'E'
 channel model, and (ii) pure independent Rayleigh
 fadings in the frequency domain. The results in terms
 of bit error rate (BER) for uncoded scenarios as a

function of the ratio $\frac{E_b}{N_0}$ (energy per bit / noise energy) are provided FIG. 4 and FIG. 5.

A clear improvement can be observed by applying our
5 decoding strategy over OFDM and MMSE SOFDM systems
using a Walsh-Hadamard spreading sequence: for a
target BER of 10^{-4} , more than 3dB is gained by compared
to MMSE SOFDM applying one or two iterations at the
three first stages.

10

This means that for the same fixed BER and a given C/I
(carrier to interference), 16QAM SOFDM with
multiresolution decoding would have the same
performance of a QPSK SOFDM MMSE transmission scheme
15 while providing an enhancement of 4 times in bit rate.
Such a significant improvement illustrates how
improved decoding schemes for existing systems can
translate directly in greater system capacity under a
given QoS constraint.

20

It will be understood that the multi-resolution decoding
algorithm for OFDM-CDMA, spread OFDM single user systems
described above provides the following advantages:
The following technical merits of the new multi-
25 resolution decoding algorithm can be highlighted:

- Low arithmetical complexity compared to existing SIC
BLAST techniques with same or better performance.
- Flexibility and scalability of the method (it is
possible to adjust the number of iterations to be
30 performed based on a performance/complexity
tradeoff).

- Can be combined into all OFDM standards as a proprietary transmission mode (since it can be viewed as a simple extension of current OFDM systems).
- 5
- Yields a significant PER performance enhancement compared to classical OFDM and minimum mean square error (MMSE) SOFDM receivers (e.g., 3dB).

Claims

1. A spread OFDM wireless communication system comprising:

- 5 at a transmitter
 means for transmitting a spread OFDM signal;
 at a receiver
 means for receiving the spread OFDM signal;
 means for equalizing the spread OFDM signal
10 means for splitting the equalized spread OFDM
 signal into a first plurality of portions
 including a first portion and a second portion;
 means for making a decision on the second
 portion
15 means for subtracting the second portion from
 the received spread OFDM signal to produce a
 first difference signal; and
 means for processing/equalizing the first
 difference signal to recover the first portion
20 of the received signal in which interference
 due to the second portion interfering terms is
 substantially reduced.
2. The system of claim 1 further comprising:
- 25 at the receiver
 means for making a decision on the first
 portion
 means for subtracting the first portion from
 the received spread OFDM signal to produce a
30 second difference signal; and
 means for processing/equalizing the second
 difference signal to recover the second portion

of the received signal in which interference due to the first portion interfering terms is substantially reduced.

5

Means for iterating the process a certain number of times (described in claim 1 and 2) with the new estimates

10 3. The system of claim 1 or 2 further comprising:
at the receiver

15 means for splitting the recovered received signal into a second plurality of portions greater in number than the first plurality of portions and including a first subsequent portion, a second subsequent portion, a third subsequent portion and a fourth subsequent portion;

20 means for subtracting the second, third and fourth subsequent portions from the received signal to produce a first subsequent difference signal; and

25 means for processing the first subsequent difference signal to recover the first subsequent portion of the recovered received signal in which interference due to the second, third and fourth portion interfering terms is substantially reduced.

30 Means for making a decision on the first portion

means for subtracting the first, third and fourth subsequent portions from the received

signal to produce a second subsequent
difference signal; and
means for processing the second subsequent
difference signal to recover the second
5 subsequent portion of the recovered received
signal in which interference due to the first,
third and fourth portion interfering terms is
substantially reduced.
Means for making a decision on the second
10 portion

means for subtracting the first, second and
fourth subsequent portions from the received
15 signal to produce a third subsequent difference
signal; and
means for processing the third subsequent
difference signal to recover the third
subsequent portion of the recovered received
20 signal in which interference due to the first,
second and fourth portion interfering terms is
substantially reduced.
Means for making a decision on the third
portion

25

means for subtracting the first, second and
third subsequent portions from the received
signal to produce a fourth subsequent
30 difference signal; and
means for processing the fourth subsequent
difference signal to recover the fourth

subsequent portion of the recovered received signal in which interference due to the first, second and third portion interfering terms is substantially reduced.

5 Means for making a decision on the fourth portion

Means for iterating the process of claim 3 .

10 Means for conducting the same algorithm described in claim 3 with a number of portions multiple of 2.

15 4. The system of claim 1,2 and 3 wherein the means for performing interference/equalization comprises:
first matrix multiplication means for multiplying by a first diagonal matrix having elements dependent on channel coefficients; and
20 second matrix multiplication means for multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.

25 5. The system of claim 1, 2, 3 or 4 wherein the means for processing comprises means for performing minimum mean square error equalization.

30 6. The system of any preceding claim wherein the means for transmitting a spread OFDM signal comprises means for spreading by performing a Walsh Hadamard transform.

7. A spread OFDM wireless communication system
comprising:

at a transmitter

means for transmitting a spread OFDM signal;

5 at a receiver

means for performing minimum mean square error
equalization having:

10 first matrix multiplication means for
multiplying by a first diagonal matrix
having elements dependent on channel
coefficients; and

second matrix multiplication means for
multiplying by a second matrix which is a
subset of a Walsh Hadamard matrix.

15

8. A receiver for use in a spread OFDM wireless communication system, the receiver comprising:

means for receiving a wireless spread OFDM signal;

5 means for splitting the received spread OFDM signal into a first plurality of portions including a first portion and a second portion;
means for subtracting the second portion from the received spread OFDM signal to produce a
10 first difference signal; and

means for processing the first difference signal to recover the first portion of the received signal in which of interference is substantially removed.

15

9. The receiver of claim 8 further comprising:

means for subtracting the first portion from the received spread OFDM signal to produce a second difference signal; and

20 means for processing the second difference signal to recover the second portion of the received signal in which interference is substantially removed.

25 10. The receiver of claim 8 or 9 further comprising:

means for splitting the recovered received signal into a second plurality of portions greater in number than the first plurality of portions and including a first subsequent
30 portion and a second subsequent portion;
means for subtracting the second subsequent portion from the recovered received signal to

produce a first subsequent difference signal;
and
means for processing the first subsequent
difference signal to recover the first
5 subsequent portion of the recovered received
signal in which interference is substantially
removed.

11. The receiver of claim 8, 9 or 10 wherein the means
10 for processing comprises means for performing minimum
mean square error equalization.

12. The receiver of claim 11 wherein the means for
performing minimum mean square error equalization
15 comprises:
first matrix multiplication means for multiplying by
a first diagonal matrix having elements dependent on
channel coefficients; and
second matrix multiplication means for multiplying
20 by a second matrix which is a subset of a Walsh
Hadamard matrix.

13. A receiver for use in a spread OFDM wireless communication system, the receiver comprising:
means for performing minimum mean square error equalization having:

5 first matrix multiplication means for
 multiplying by a first diagonal matrix having
 elements dependent on channel coefficients; and
 second matrix multiplication means for
 multiplying by a second matrix which is a
10 subset of a Walsh Hadamard matrix.

14. A method of operating a receiver in a spread OFDM
wireless communication method comprising:

5 receiving a wireless spread OFDM signal;
splitting the received spread OFDM signal into
a first plurality of portions including a first
portion and a second portion;
subtracting the second portion from the
received spread OFDM signal to produce a first
difference signal; and
10 processing the first difference signal to
recover the first portion of the received
signal in which of interference is
substantially removed.

15 15. The method of claim 14 further comprising:
subtracting the first portion from the received
spread OFDM signal to produce a second
difference signal; and
processing the second difference signal to
20 recover the second portion of the received
signal in which interference is substantially
removed.

16. The method of claim 14 or 15 further comprising:
25 splitting the recovered received signal into a
second plurality of portions greater in number
than the first plurality of portions and
including a first subsequent portion and a
second subsequent portion;
30 subtracting the second subsequent portion from
the recovered received signal to produce a
first subsequent difference signal; and

processing the first subsequent difference
signal to recover the first subsequent portion
of the recovered received signal in which
interference is substantially removed.

5

17. The method of claim 14, 15 or 16 wherein the step of
processing comprises performing minimum mean square error
equalization.

10 18. The method of claim 17 wherein the step of
performing minimum mean square error equalization
comprises:

15 multiplying by a first diagonal matrix having
elements dependent on channel coefficients; and
multiplying by a second matrix which is a subset of
a Walsh Hadamard matrix.

19. A method for performing minimum mean square error equalization in a spread OFDM wireless communication system, the method comprising:

- 5 multiplying by a first diagonal matrix having elements dependent on channel coefficients; and
- multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.

Abstract

SYSTEM, RECEIVER AND METHOD OF OPERATION FOR SPREAD OFDM
WIRELESS COMMUNICATION

5

A system (110-190), receiver (160-190) and method of operation for spread OFDM wireless communication (single user OFDM-CDMA with cyclic-prefix) by:

- Equalizing the splitting received spread OFDM signal (y)
- 10 Splitting the equalized received spread OFDM signal (y) into first and second portions (\hat{s}_1, \hat{s}_2); making a decision on the second portion and subtracting the second portion from the received spread OFDM signal to produce a first difference signal; processing the first difference signal
- 15 to recover the first portion of the received signal in which of the symbol interfering terms of the second portion are substantially reduced; making a decision and subtracting the first portion from the received spread OFDM signal to produce a second difference signal; and
- 20 processing the second difference signal to recover the second portion of the received signal in which the symbol interfering terms of the first portion are substantially reduced. The process is iterated extensively at this stage. In a second stage, the recovered received signal
- 25 is split into a greater number of portions (e.g., 4), and processed similarly to further reduce interference. The same mechanisms can be applied to blocks of reduced size divided by 8, 16 etc.) leading to a higher resolution of the decoding and a tree-like structure.
- 30 Also, minimum mean square error equalization is performed by multiplying by a first diagonal matrix having elements dependent on channel coefficients; and multiplying by a

second matrix which is a subset of a Walsh Hadamard matrix.

This provides low arithmetical complexity, it is possible to adjust the number of iterations to be performed based
5 on a performance/complexity tradeoff, it can be viewed as a simple extension of current OFDM systems, and it yields a significant PER performance enhancement (e.g., 3dB).

Figs 1 & 2

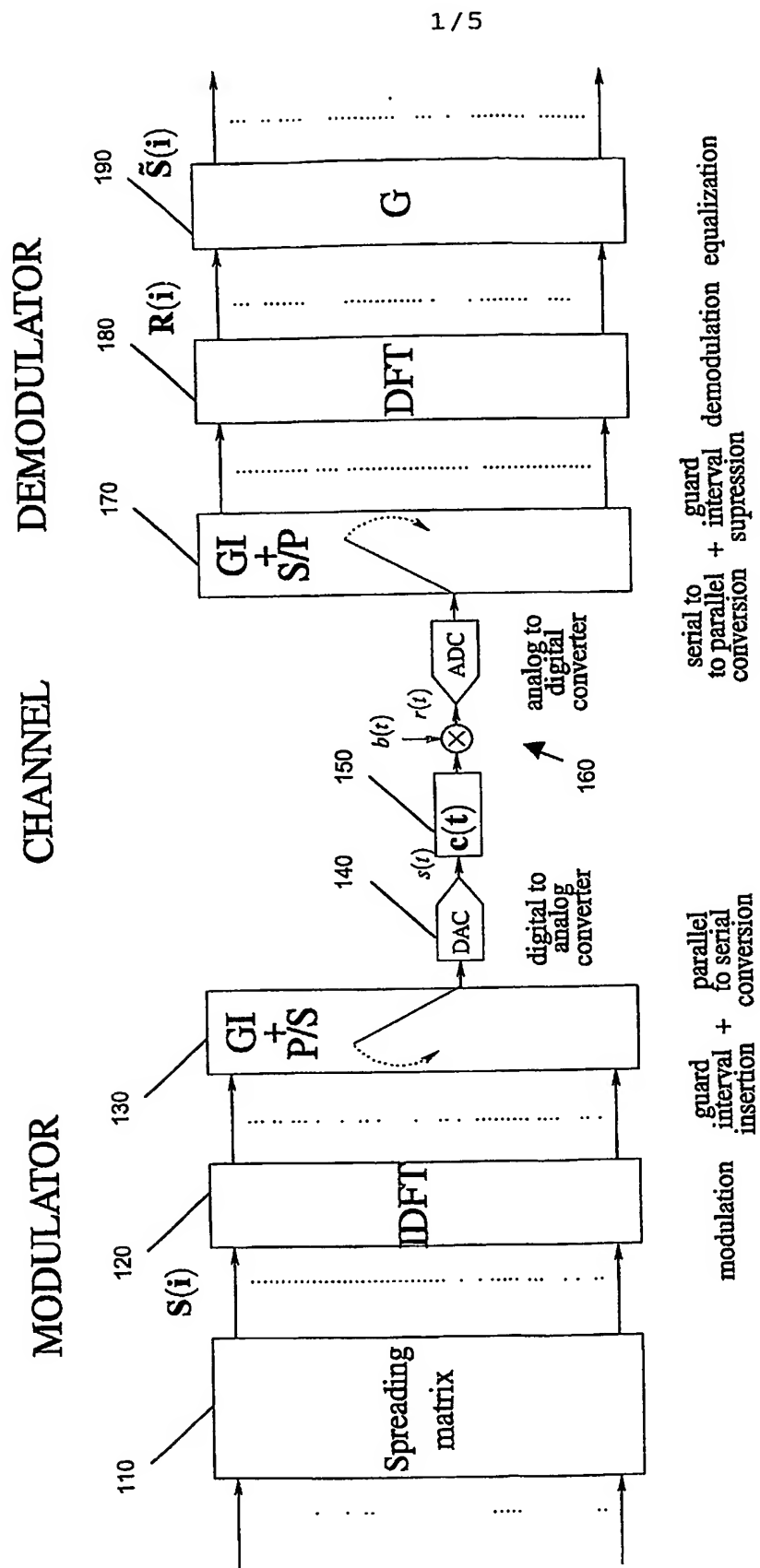


FIG. 1

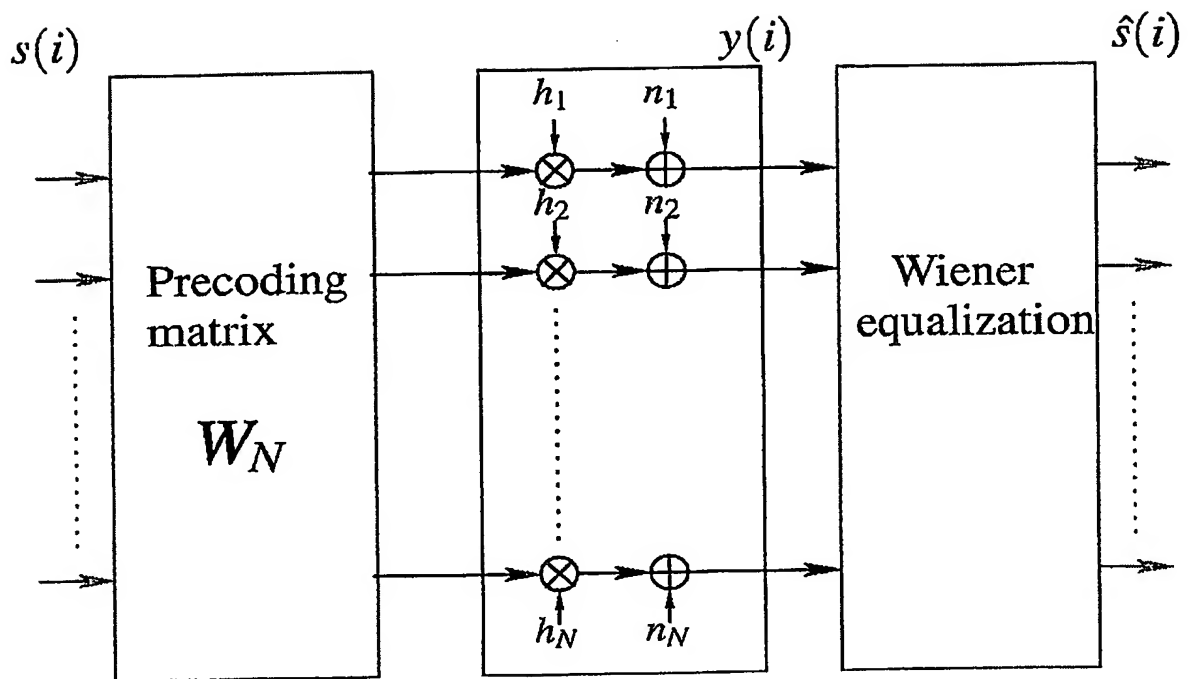


FIG. 2

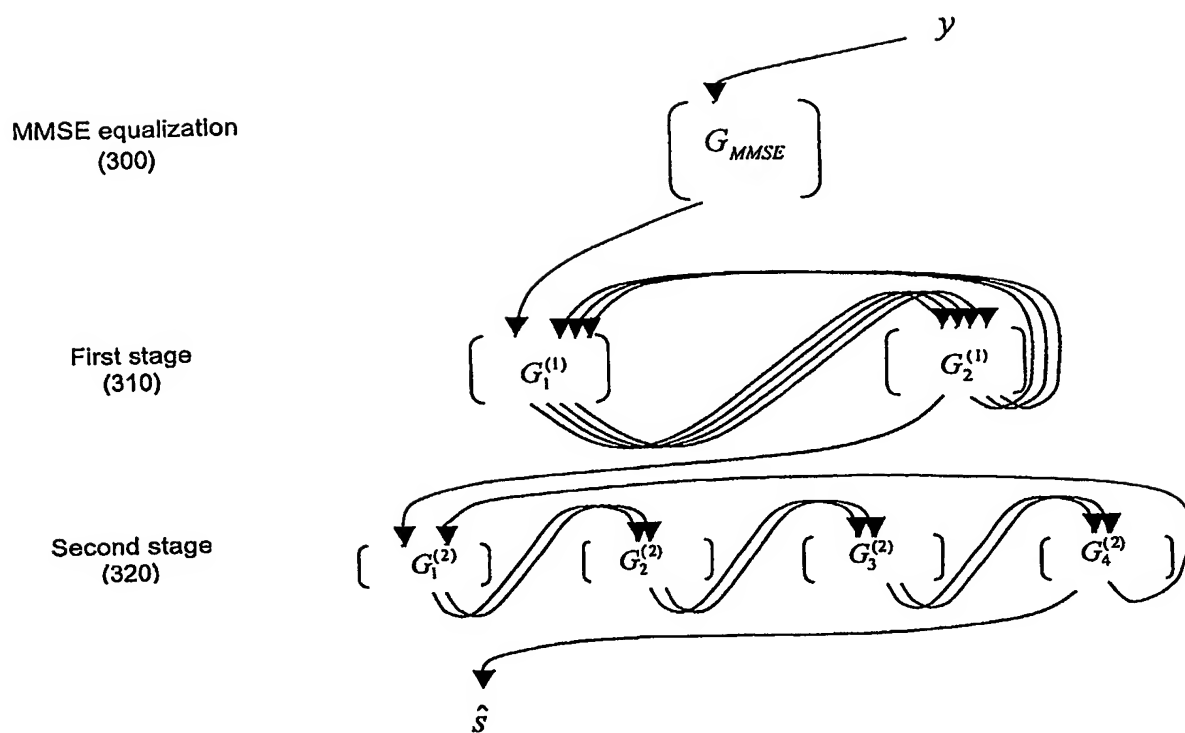


FIG. 3

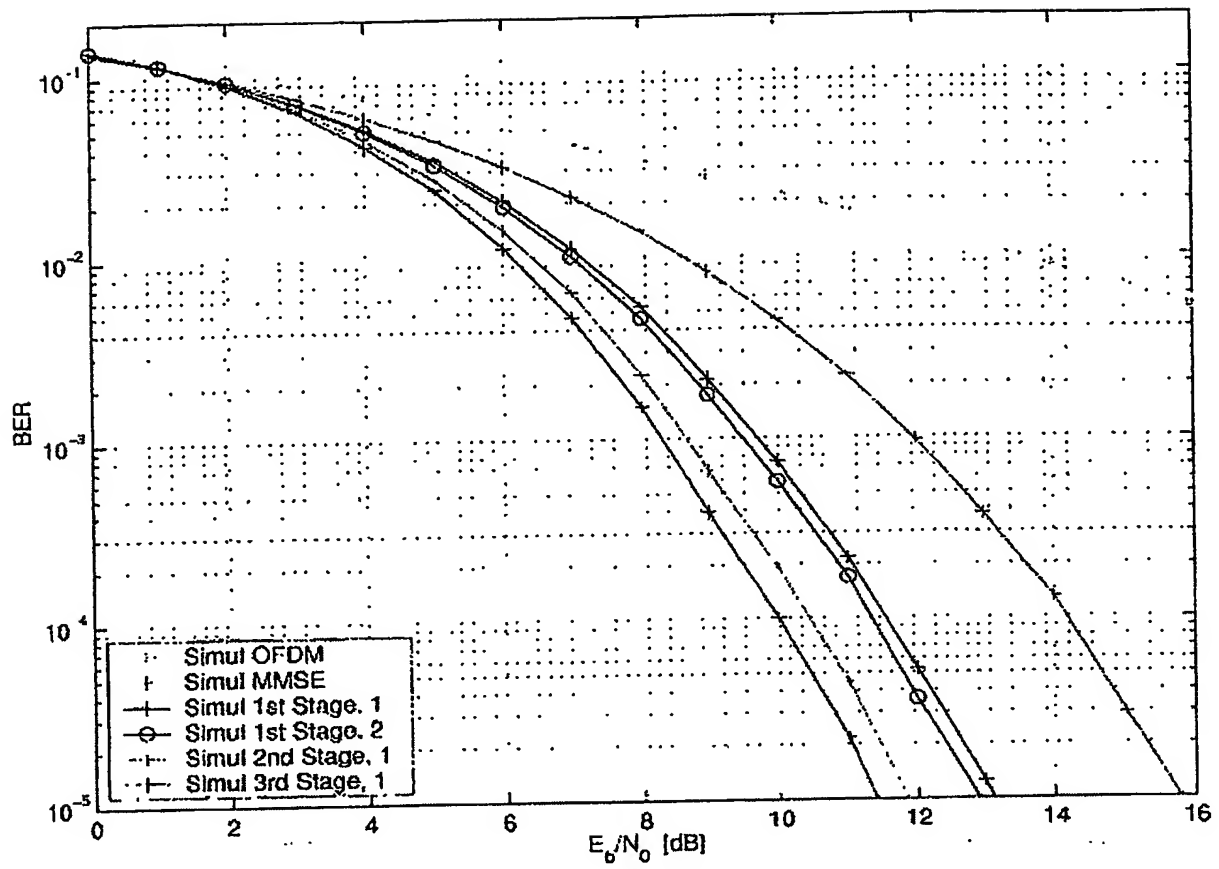


FIG. 4

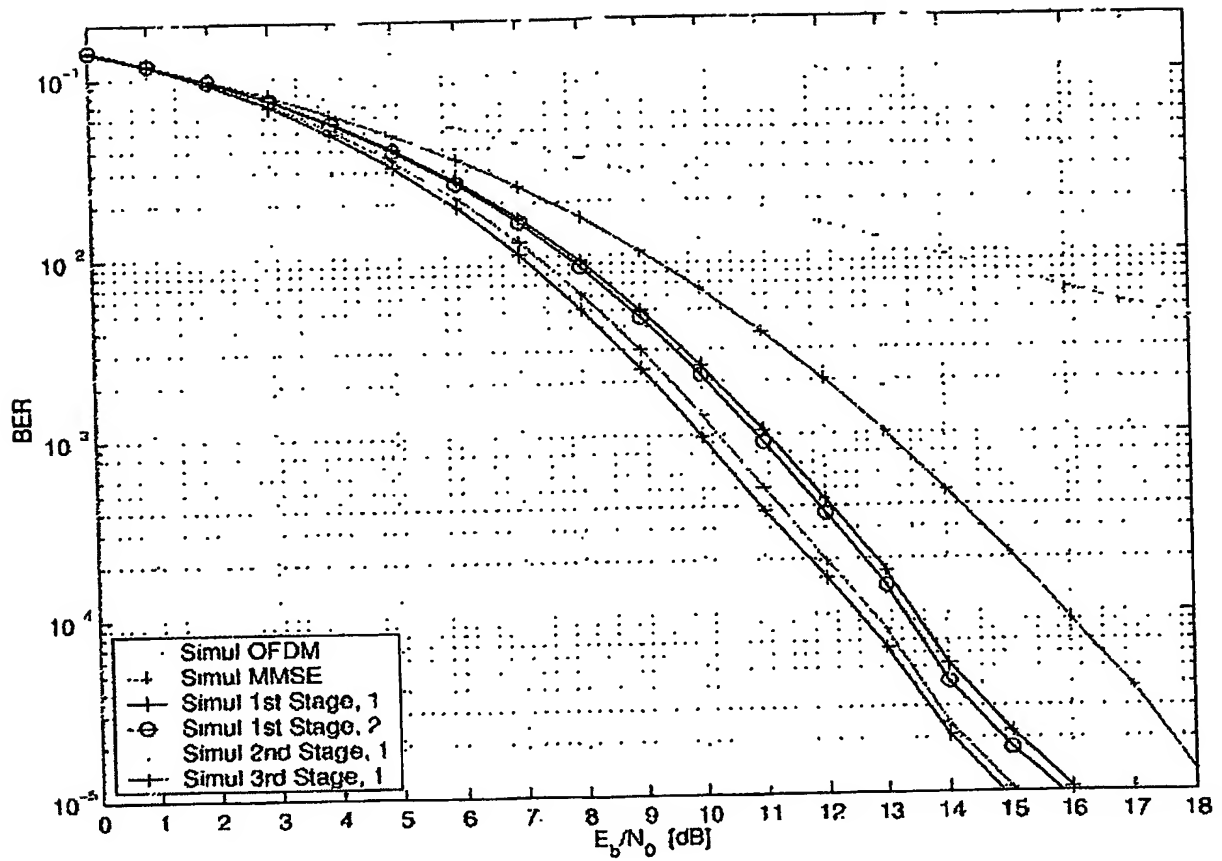


FIG. 5

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